

# Country Review: USA

10th Micromachine Summit, Grenoble, France  
May 3-5 2004



US Delegation: Michael Gaitan, NIST  
Steve Walsh, UNM  
Tom Cellucci, Zyvex  
Bob Sulouff, Analog Devices

# Outline

- Regional Snapshot
- Government Programs
- Standardization

## Places to watch

**Arizona**  
Arizona is down but not out as last year's fourth-place state recuperates from corporate cuts, a drop in SBIR activity and the loss of R&D companies.

**Colorado**  
It's more a question of when, not if, Colorado breaks into the top 10. The recent award of an NSF-funded engineering center should help.

**Maryland**  
Last year's No. 6 state slipped to the 11th spot after other states capitalized on new funding opportunities.

**Minnesota**  
Companies like 3M, Medtronic and related businesses keep the state's innovation motor humming.

**New Jersey**  
New Jersey consistently flirts with the top 10 but high costs put it in the lower bracket.

**North Carolina**  
Too much of North Carolina's stellar research seems to languish in the labs, but that could change.

**Washington**  
Expect Washington to pick up steam as it deepens partnerships with neighboring Oregon.

# Top 10: Small tech's hot spots

**1. California**  
It's the appetite that really counts. Sure, California has the right ingredients — ideas, innovators, investors — and a recipe for mixing them successfully. But its stomach for risk is unrivaled. **2003 ranking: 1**

**3. New Mexico**  
Is New Mexico treading water or riding a wave? The success of innovators who sprang from the state's font of knowledge — its two national labs — offset a drop in research. **2003 ranking: 3**

**5. Texas**  
The Texas business scene offers a mix of old and new blood in the most affordable of the top 10 states. But can it translate its inexpensive labor into the skilled work force that those companies will need to grow? **2003 ranking: 5**

**6. Illinois**  
Illinois could be explosive in coming years, or it could just implode. It stands out for research but it's been slow to convert that asset into commerce. **2003 ranking: 8**

**8. Michigan**  
It's the Mostate, and we're not talking just motors. Its ability to pull more federal R&D dollars into the state could buoy its growth. **2003 ranking: 9**

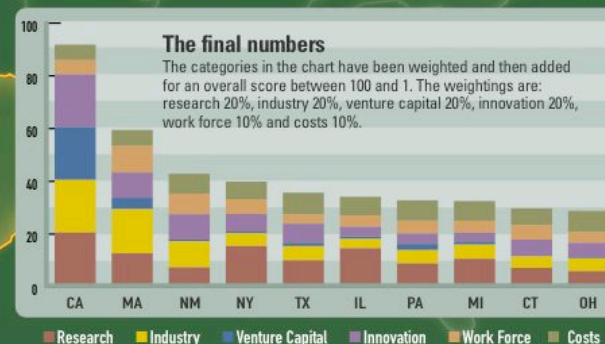
**4. New York**  
The Seabiscuit of small tech. New York turned it on in 2003, winning laurels as diverse as a nano college and continued support for its DOE center. Corporate thoroughbreds like IBM add to its success. **2003 ranking: 7**

**2. Massachusetts**  
Here's a state that knows how to do more with less. Others grabbed a larger slice of the research pie, but the Minutemen are proving better at turning even the crumbs into products. **2003 ranking: 2**

**9. Connecticut**  
Connecticut's proximity to New York and Massachusetts and venerable names like Yale and Praxair help to gain a foothold in small tech. **2003 ranking: 14**

**7. Pennsylvania**  
Pennsylvania builds off its strengths in micro and nanoscale technologies. That expertise combined with partnerships within and without the state make it a consistent contender. **2003 ranking: 10**

**10. Ohio**  
Strong engineering schools coupled with medical, space and military labs and dozens of innovative companies help elevate Ohio into the elite 10. **2003 ranking: 17**

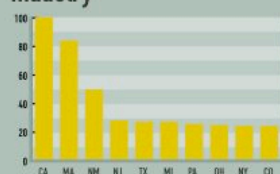


**Sources:** National Science Foundation, National Institutes of Health, Departments of Defense, Energy and Commerce, Environmental Protection Agency, NASA, U.S. Census Bureau, U.S. Patent and Trademark Office, Bureau of Labor Statistics, PricewaterhouseCoopers/Thomson Financial Venture Economics/National Venture Capital Association MoneyTree Survey and Small Times research. Research by Candace Stuart and David Forman, with support from Gretchen McNeely and Karen Van Antwerp

## Research



## Industry



## Venture Capital



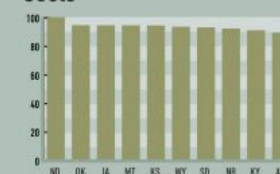
## Innovation



## Work Force



## Costs



We rank every state in each of the categories above.

Here are the states that made the Top 10 by category.

# US Investment in Nanotechnology



United States Federal Government investment in nanotechnology R&D

1997: \$116M

2004: \$849M

Companies are investing equal rate, according to estimates.

source: <http://www.nano.gov>



# National Science Foundation

- Supports university research
  - Diverse portfolio of programs
- Sponsors studies and workshops
  - Workshops on nanotechnology grand challenges
- Fosters development of scientific technologies for research
  - National Nanotechnology Infrastructure Network (NNIN)
- Budget: \$5.74B requested in 2005



# **National Nanotechnology Infrastructure Network**

- A partnership of thirteen user facilities
- Hands-on access to nanofab tools
- Supported by the National Science Foundation (NSF)
- NNIN Director: Prof. Sandip Tiwari, Cornell

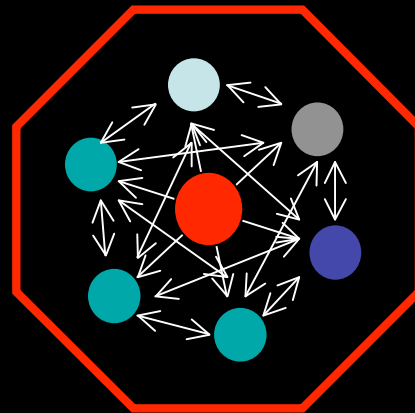
Cornell University  
Stanford University  
University of Michigan  
Georgia Institute of Technology  
University of Washington  
UC Santa Barbara  
University of Minnesota  
University of New Mexico  
UT Austin  
Harvard University  
Howard University  
North Carolina State University

<http://www.nnin.org>

# Fabrication Choices



NNIN



MEMS Exchange

MEMS Foundries

MEMS Exchange coordinates a system of facilities  
that provide specialized fabrication steps

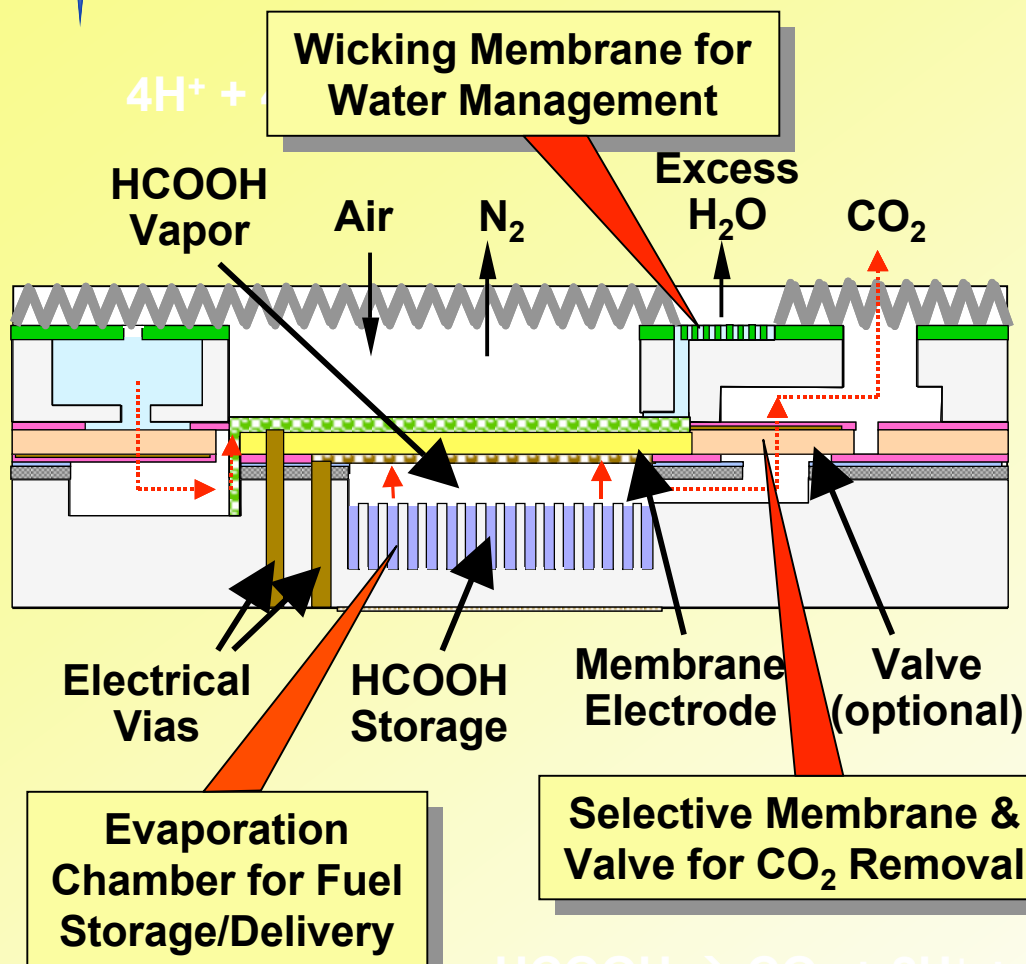


# DARPA: New Programs

- Harsh Environment Robust Micromechanical Technology
- Micro-Antenna Arrays
- Micro-Electric Propulsion
- Micro Gas Analyzers
- Radio Isotope Micro-Power Sources
- Chip Scale Atomic Clock



# Formic Acid Micro Fuel Cell



## Advantages:

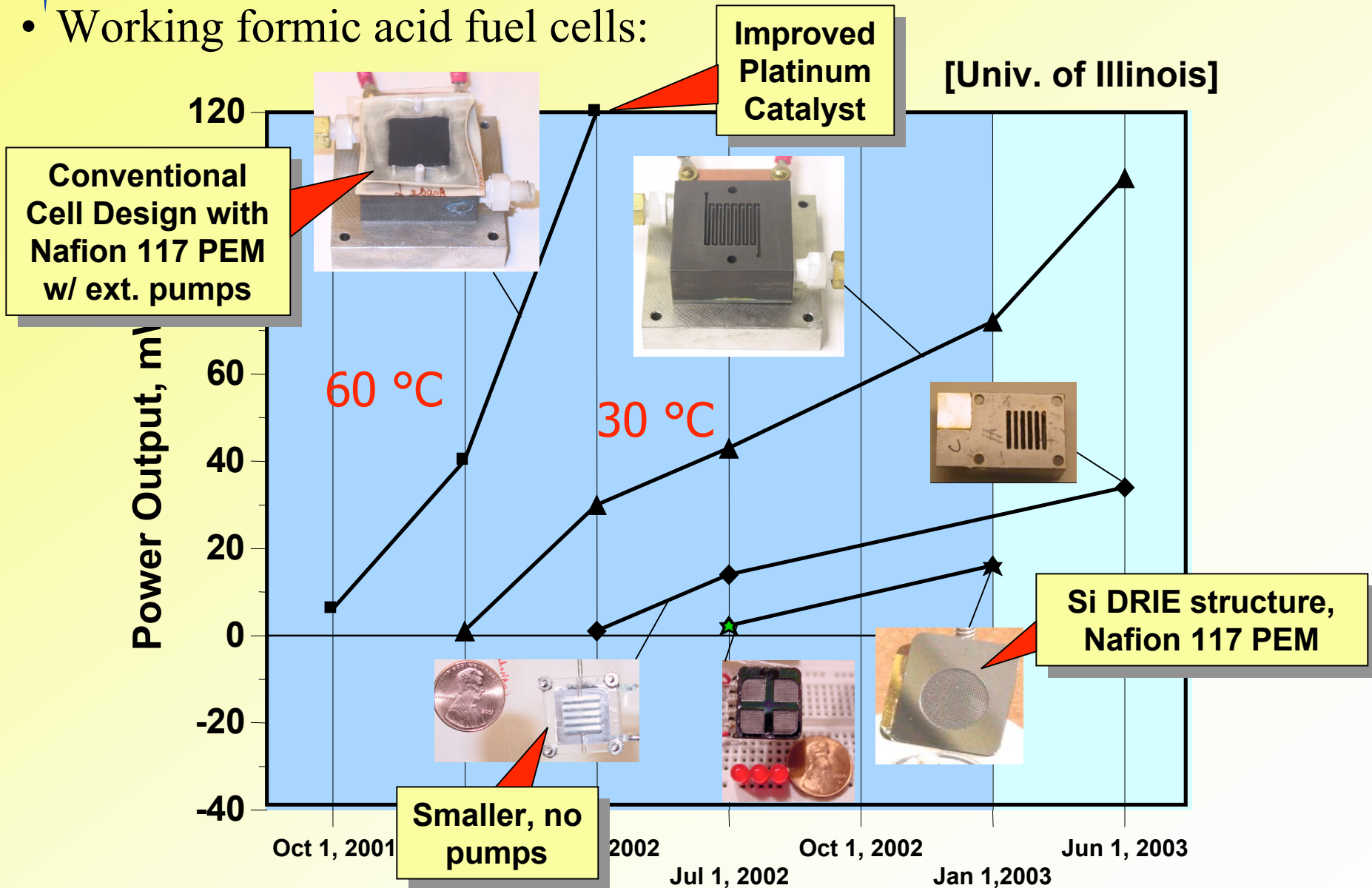
- Efficient operation at ambient temperature
  - no thermal signature
  - no need for thermal isolation
- Very high reaction rate
  - 300X larger current density than methanol
  - allows smaller size
- Formic acid commonly found in nature (in insects and animal waste)

UIUC team: Formic acid operates over wide concentration range without crossover in Nafion 117 PEM



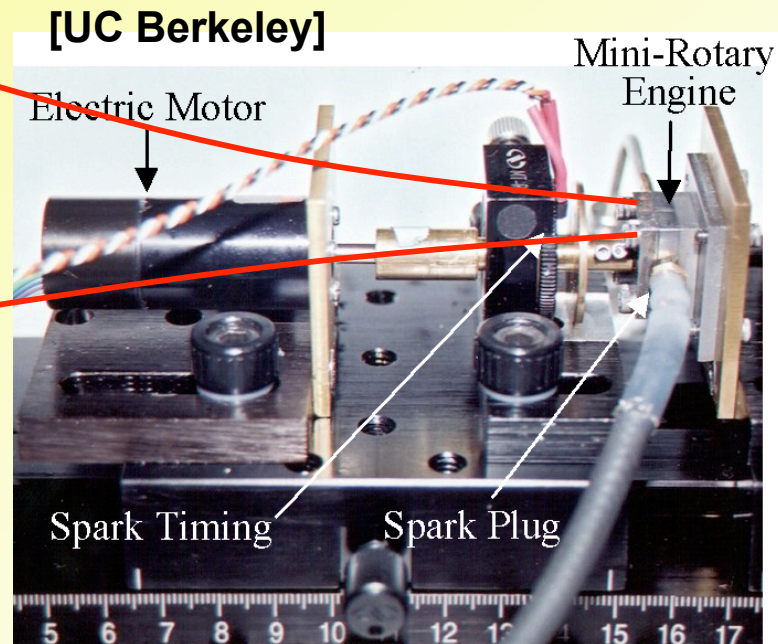
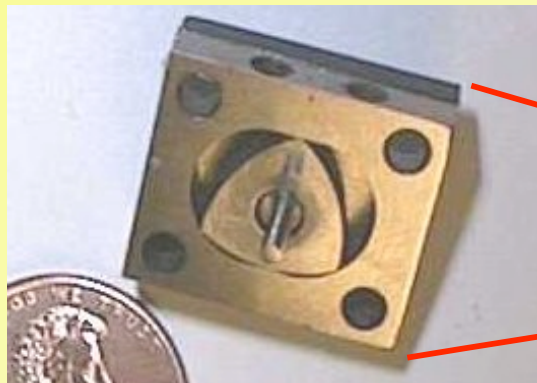
# Performance Continues To Improve

- Working formic acid fuel cells:

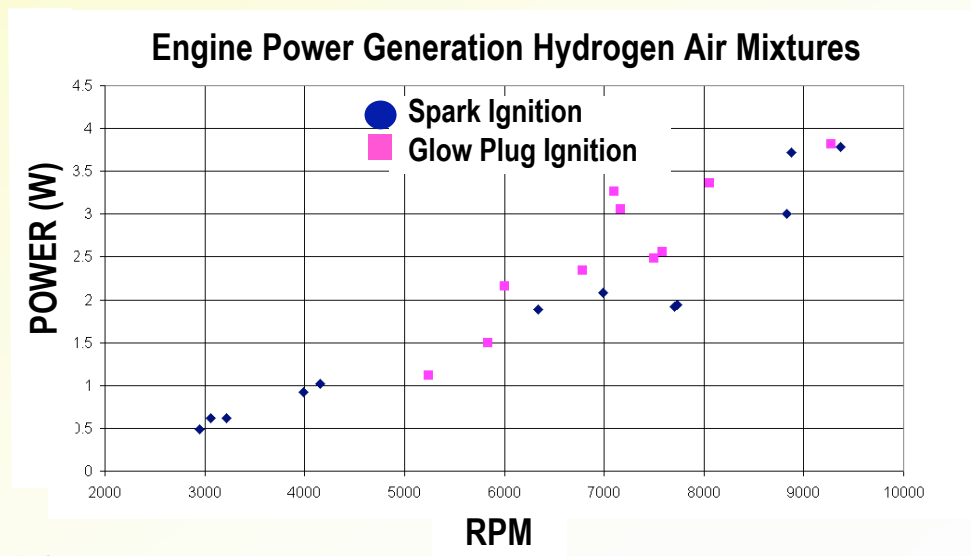




# Millimeter-Scale Rotary Engine Demo



- Demonstrated feasibility of a small-scale ( $\sim 1$  cm) engine that potentially capable of generating 10-100W of power
- Power Output Results:
  - $\sim 4$ W @ 9300RPM
  - both glowplug and spark ignition demonstrated
- Industry Transition
  - improve performance
  - fuel flexibility



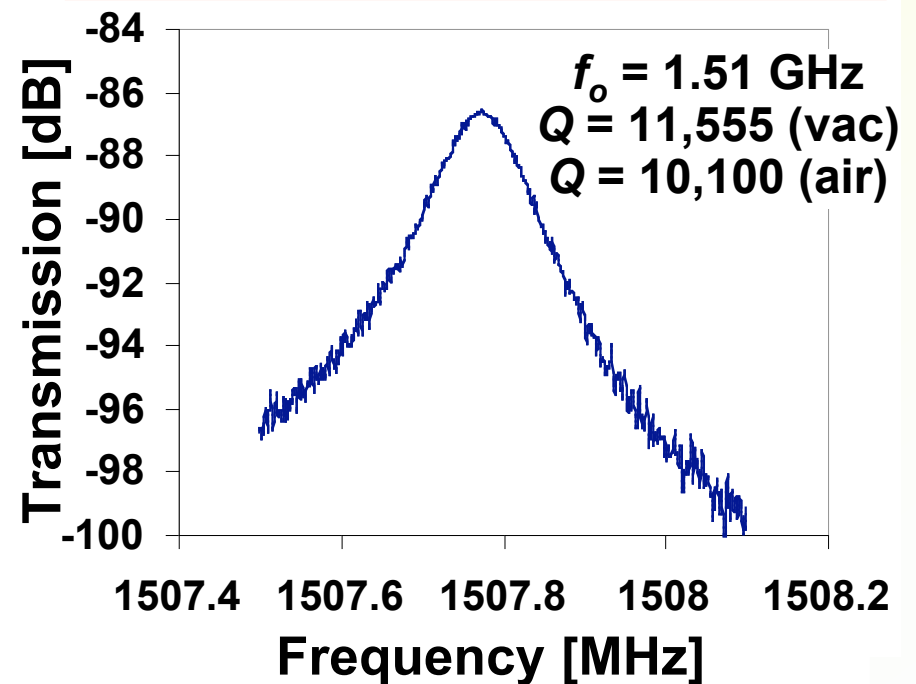
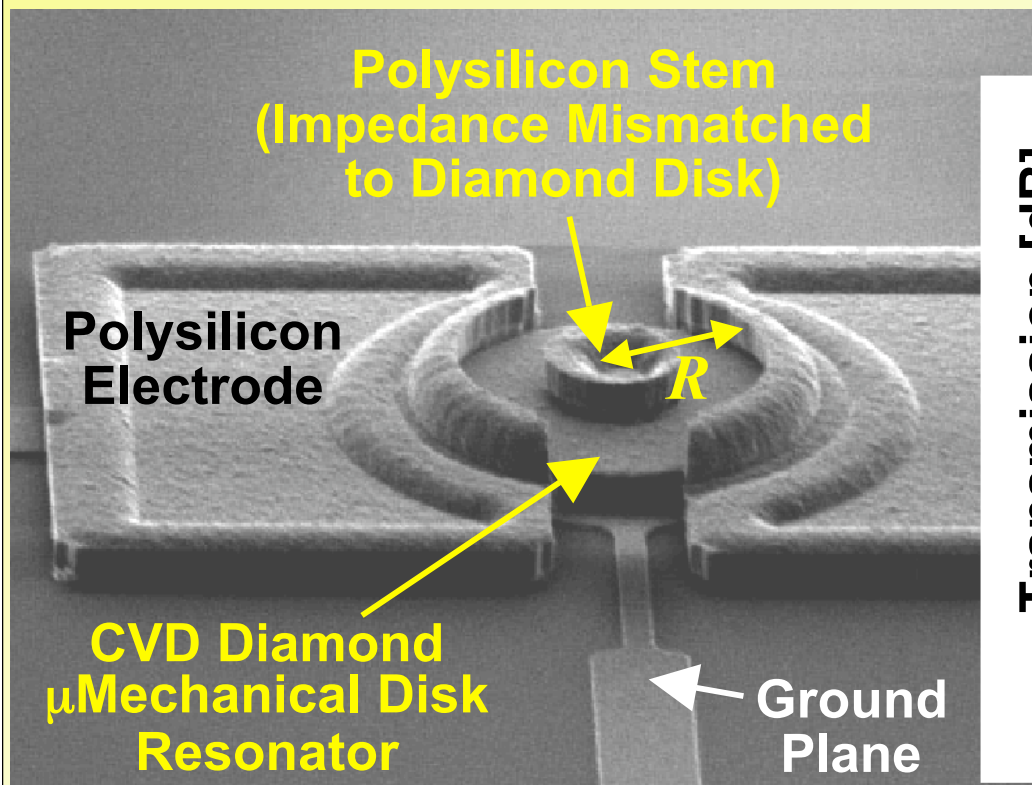


# 1.51-GHz, $Q=11,555$ Nanocrystalline Diamond Disk $\mu$ Mechanical Resonator

- Impedance-mismatched stem for reduced anchor dissipation
- Operated in the 2<sup>nd</sup> radial-contour mode
- $Q \sim 11,555$  in vacuum;  $Q \sim 10,100$  seen even in air
- Below: 20 mm diameter disk

## Design/Performance:

$R=10\mu\text{m}$ ,  $t=2.2\mu\text{m}$ ,  $d=800\text{\AA}$ ,  $V_p=7\text{V}$   
 $f_o=1.51\text{ GHz}$  (2<sup>nd</sup> mode),  $Q=11,555$



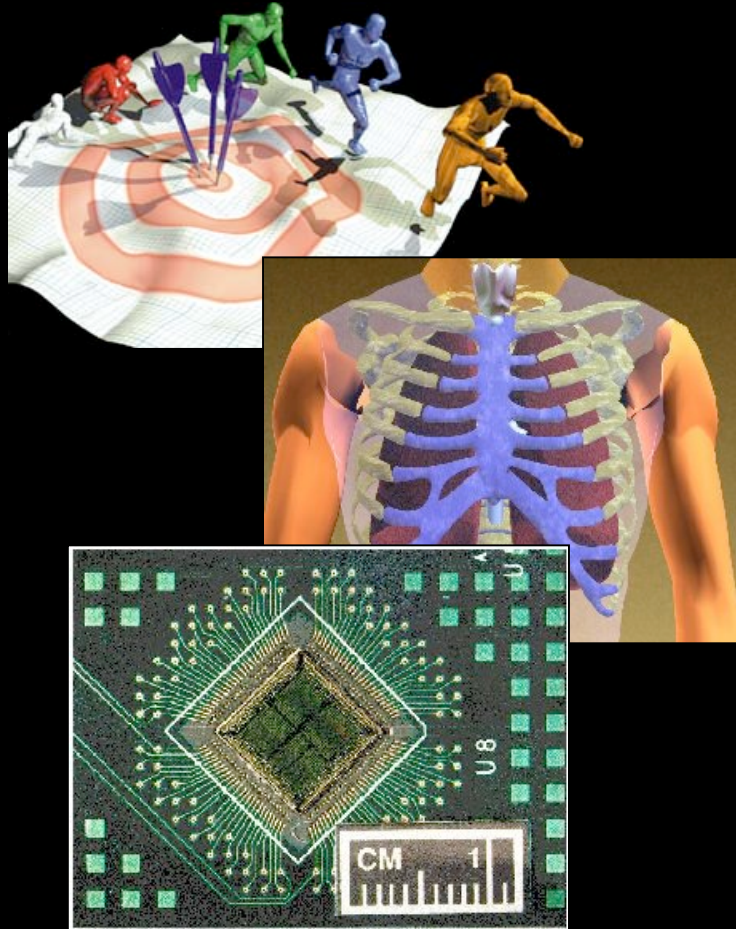
[Wang, Nguyen 2003]



**Extramural: Advanced Technology Program --  
\$4 billion in cost-shared partnerships with  
industry since 1990**

**Intramural: NIST Laboratories -- National  
measurement standards**

# Advanced Technology Program



- **“DNA Chips”** - new technology for cheap, rapid genetic analysis
- **Tissue Engineering** - new materials to repair damaged ligaments and tendons: several billion dollar impact
- **Auto Body Consortium** - improved fitting of parts to save money for manufacturers and consumers

[www.atp.nist.gov](http://www.atp.nist.gov)

# NIST Laboratories

## Measurement Research

*2,200 publications/year*

## Standard Reference Data

*90 types available*

*5,500 units sold/ year*

## Standard Reference Materials

*1,300 products available*

*31,000 units sold/year*

## Calibrations and Tests

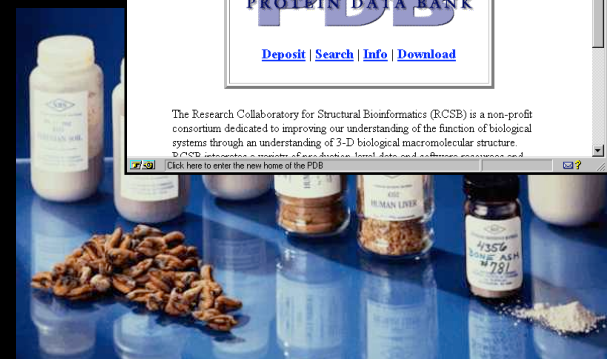
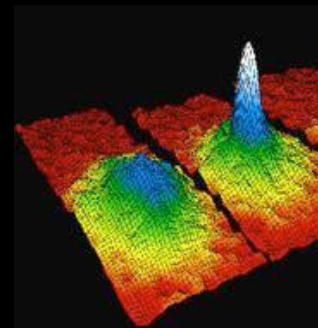
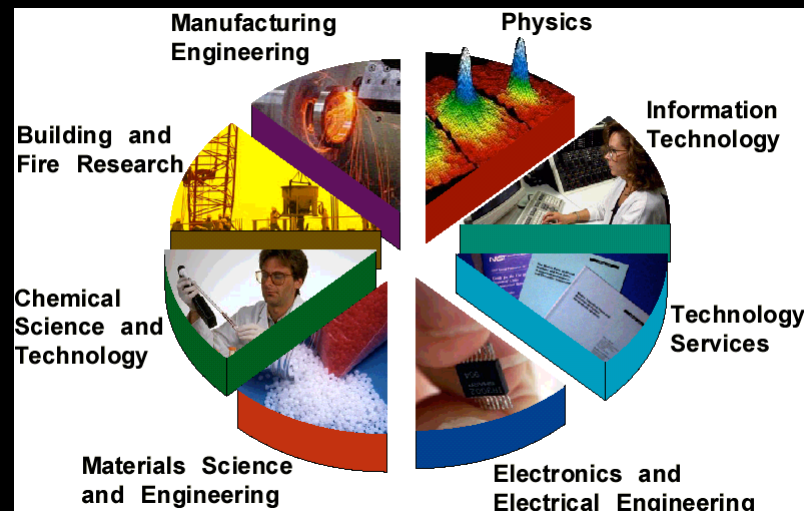
*3,000 items calibrated/year*

## Laboratory Accreditation

*819 accreditations*

## Standards Committees

*440 NIST staff, 970 committees*

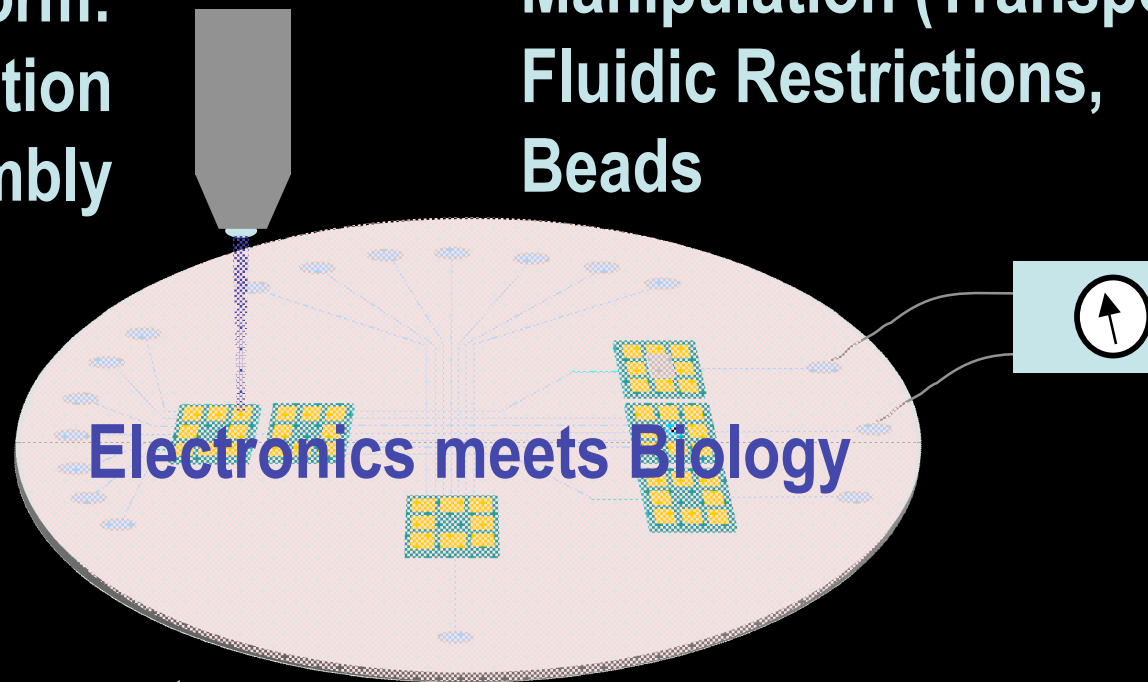


# NanoBioTechnology

## Single Molecule Manipulation and Measurement: SM<sup>3</sup>

**Platform:**  
**Nanofabrication**  
**Molecular Assembly**

**Manipulation (Transport):**  
**Fluidic Restrictions,**  
**Beads**

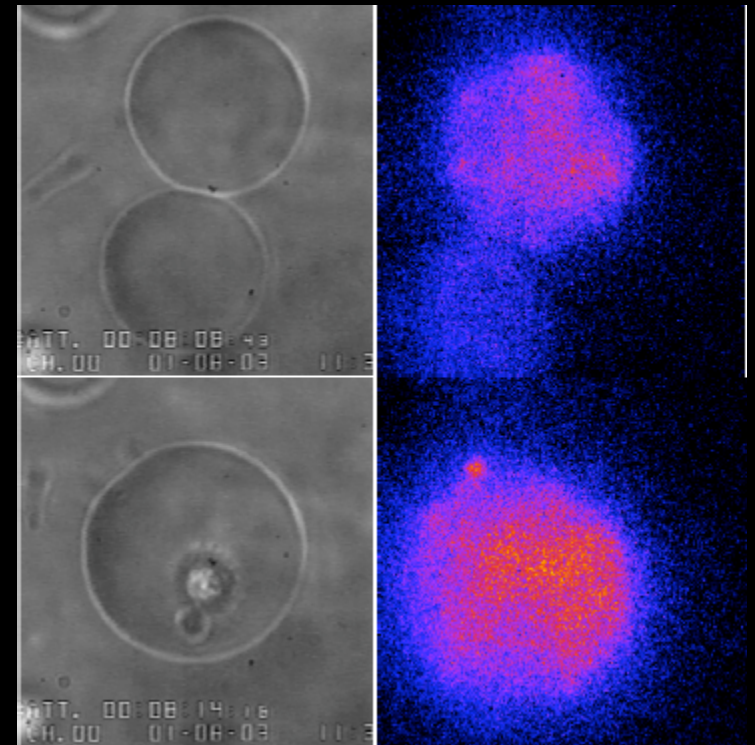


**Measurements:**  
**Electronic, Optical, Force**

**Manipulation (Capture):**  
**Vials, Beads, Arrays**

# Liposomes

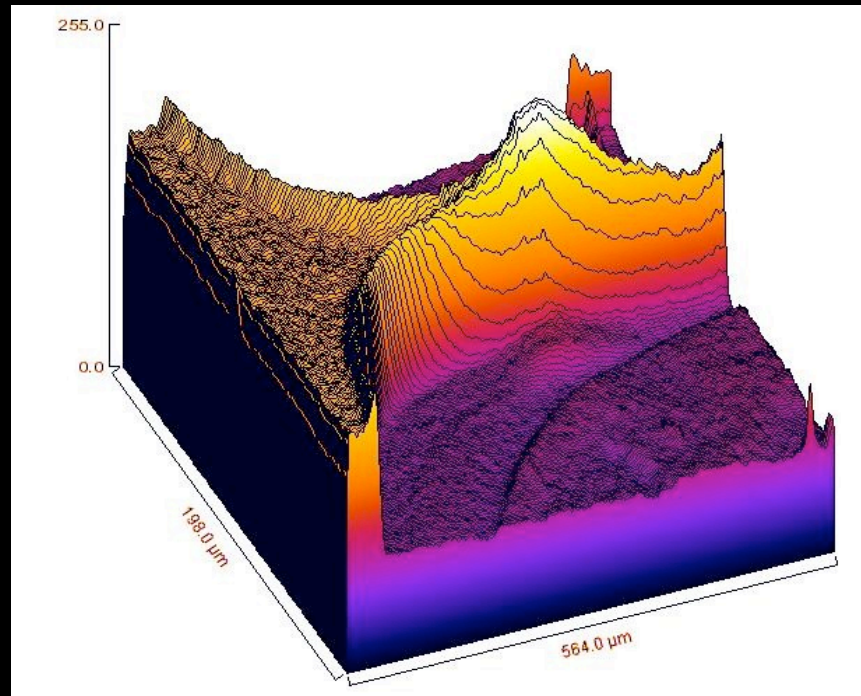
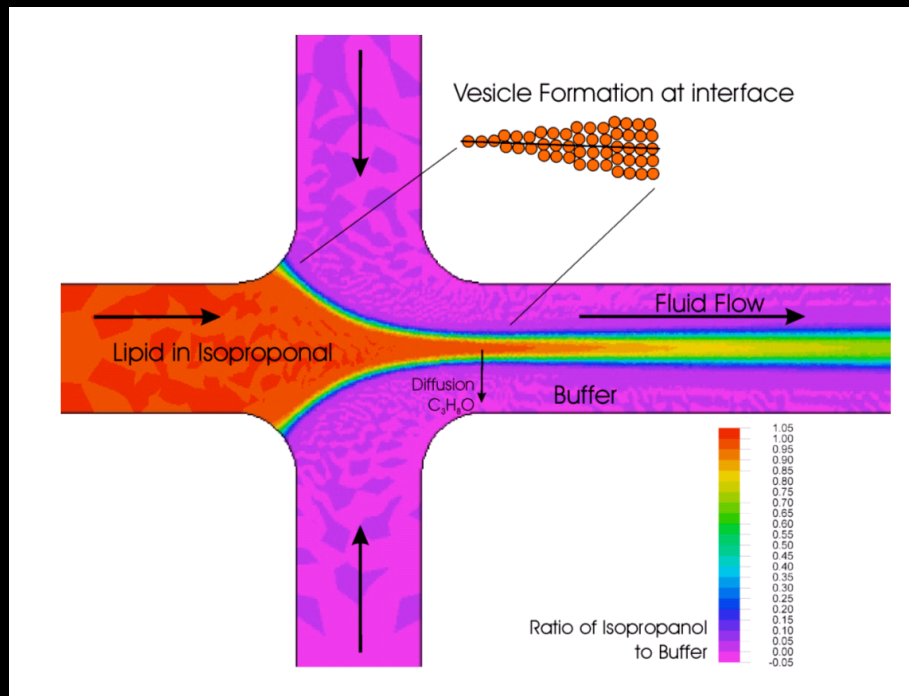
## Nanoreaction Vials



# Nanoparticle Self-Assembly

## Liposomes as Nanovials

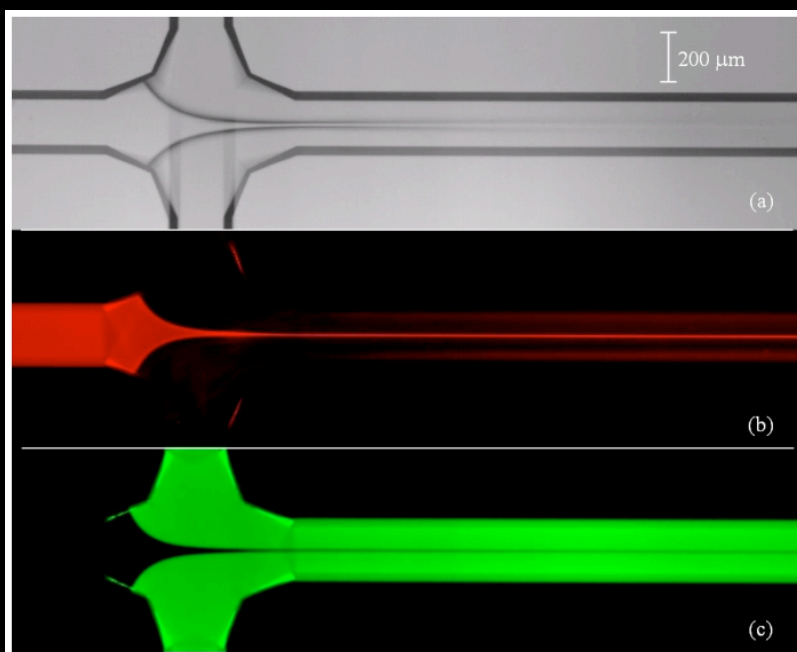
### Microfluidic Device



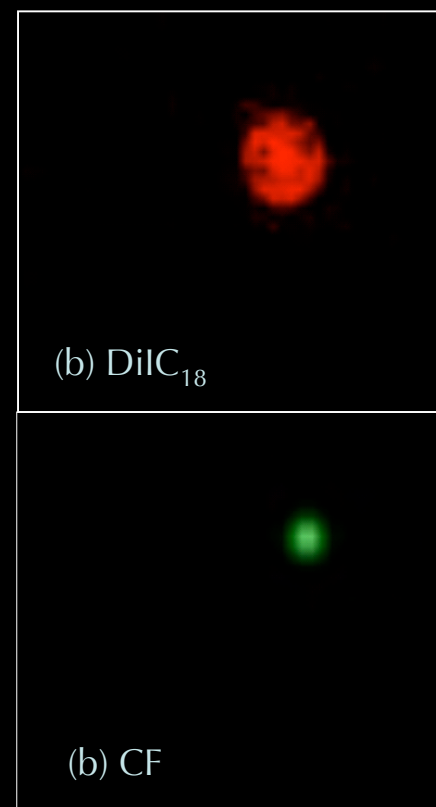
*Single Molecule Manipulation and Measurement: SM3*

# Nanoparticle Self-Assembly

## Liposomes as Nanovials



*JACS, 126, 2674-2674, March 2004*



# MEMS Technology Timeline

Commercial Growth

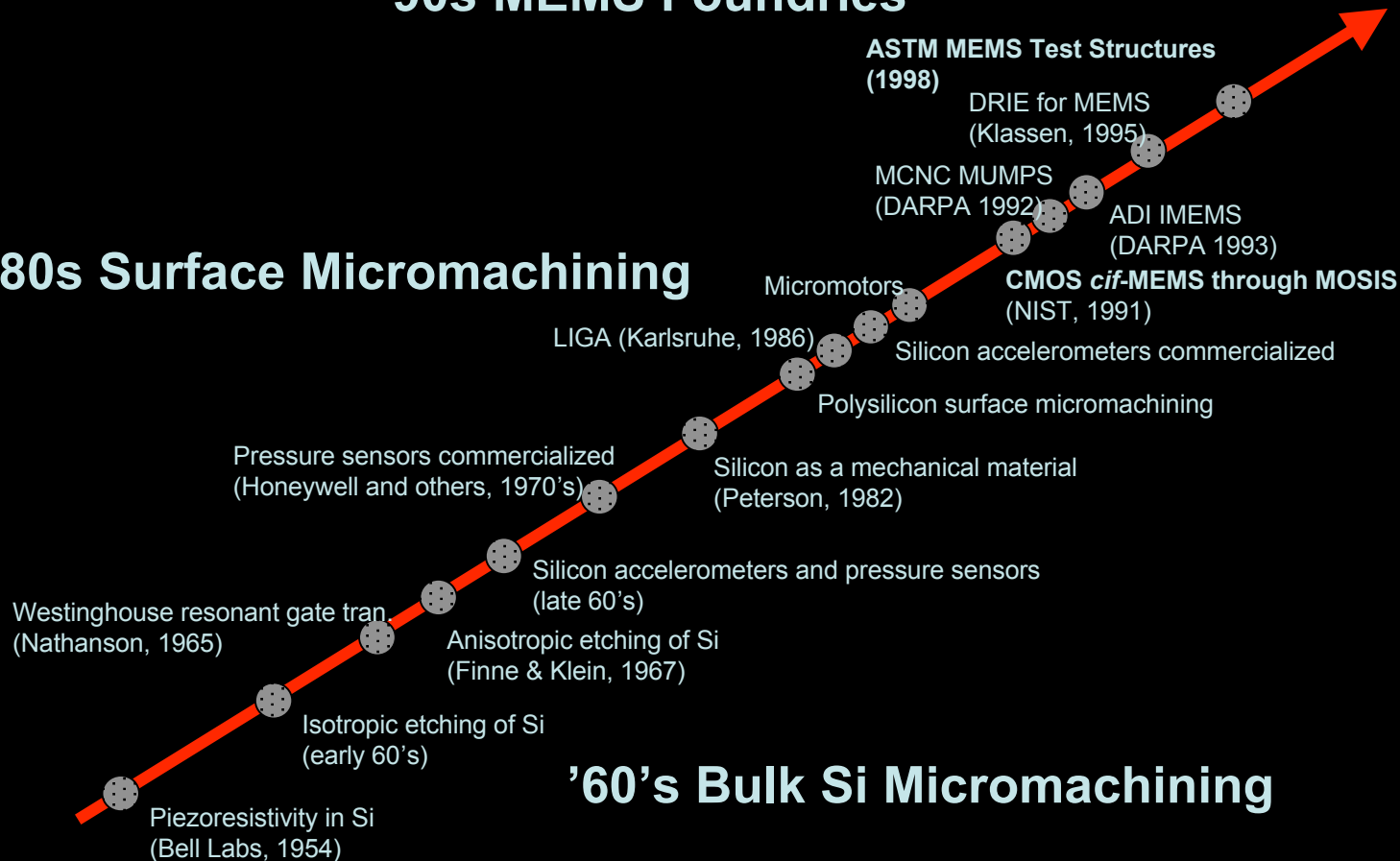
Standards

Nano

## '90s MEMS Foundries

## '80s Surface Micromachining

## '60's Bulk Si Micromachining



# Standardization

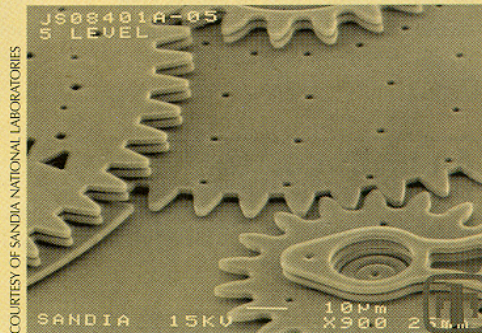
## Task Group Descends On Micro-Technology

An ASTM task group is working with tiny mechanical parts smaller than the width of a human hair. Work on microelectromechanical systems (MEMS) standardization is under way in Task Group E08.05.03 on Structural Films and Electronic Materials, under Subcommittee E08.05 on Cyclic Deformation and Fatigue Crack Formation, in Committee E-8 on Fatigue and Fracture. Scientists experienced in fatigue and fracture and/or creep-process are sought for development of MEMS test methods.

In these tiny systems, barely visible gears, hinges, motors, and other mechanical components are manipulated by micro-tweezers and probes, and viewed with scanning electron microscopes. "Imagine everything in day-to-day life being miniaturized: gears, wheels, motors, turbine engines, everything. My whole fatigue testing machine fits on a silicon chip a few hundred microns square," said Task Group Chairman Chris Muhlstein, a materials scientist in the Materials Science and Engineering Department, University of California, Berkeley.

MEMS are made from combinations of metals, ceramics, and polymers. "The little nozzles on your ink-jet cartridge are probably one of the

(CONTINUED ON NEXT PAGE)



Smaller than the width of a human hair, microscopic gears of this type are used in polysilicon microengine transmissions, an important application for new ASTM standards.

- ASTM (American Society for Testing and Materials) Task Group E08.05.03 established in 1998
- Activities
  - Residual Stress Standard Test Method (Round Robin in Progress)
  - Elastic Modulus Standard Test Method

# Published ASTM Standards



E2244: In-Plane Length Measurements

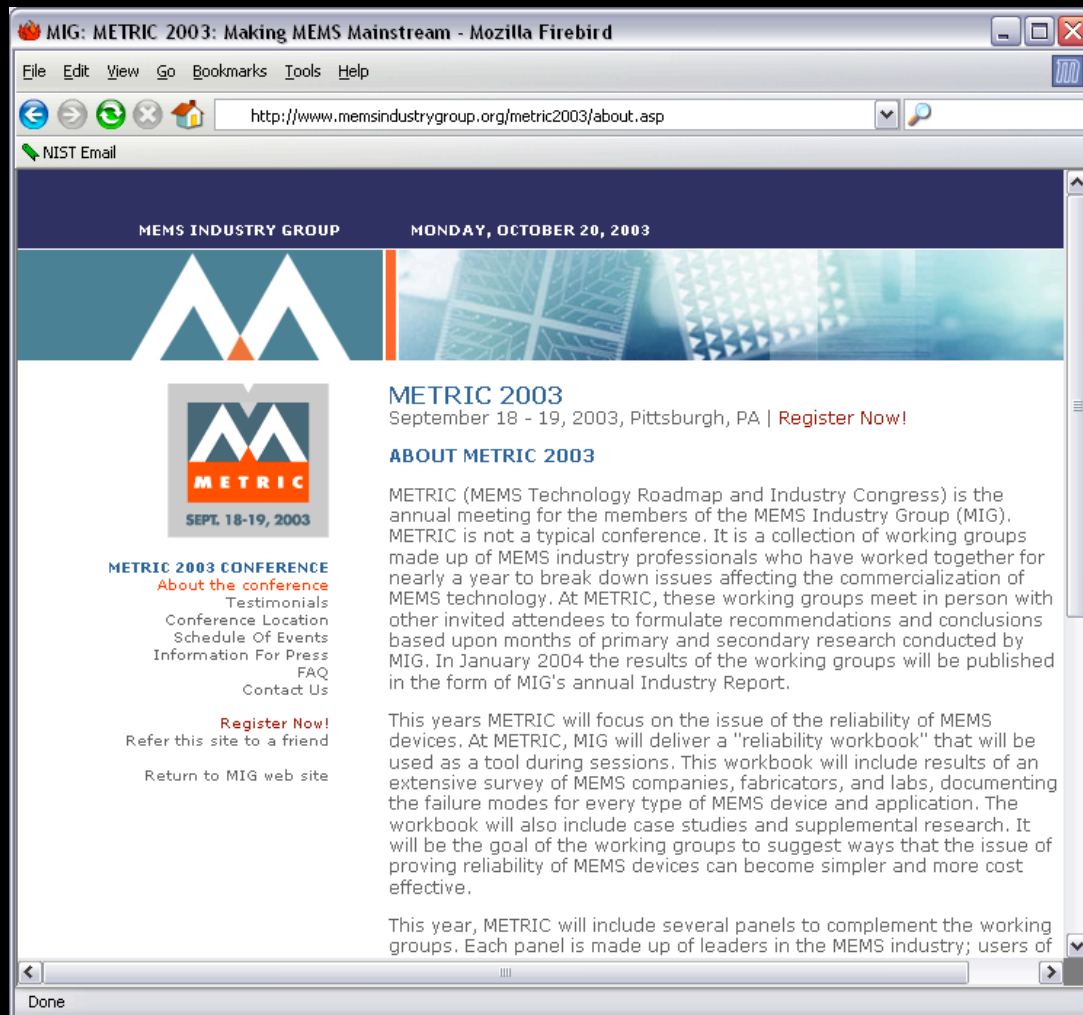
E2245: Residual Strain Measurements

E2246: Strain Gradient Measurements

Round robin experiment is now in progress

- Google: MEMS Round Robin  
- <http://www.eeel.nist.gov/812/44.htm>

# MEMS Industry Group



## METRIC 2003 Reliability Workshop

Held in Pittsburgh PA  
Sept 2003

Preparing for  
**METRIC 2004 in  
September**

Topic: Accelerated  
Lifetime Testing

# SEMI: International MEMS Steering Group (IMSG)



**Equipment Industry  
Group**

**Upcoming Workshops  
(US)**

**ASMC**

**May 4-6 2004**

**SEMICON West:  
Summer 2004**

# A Presidential Perspective on the Commercialization of Nanotechnologies

## *“A Fantastic Voyage”*

Dr. Steven Walsh

Dr. Kees Eijkel

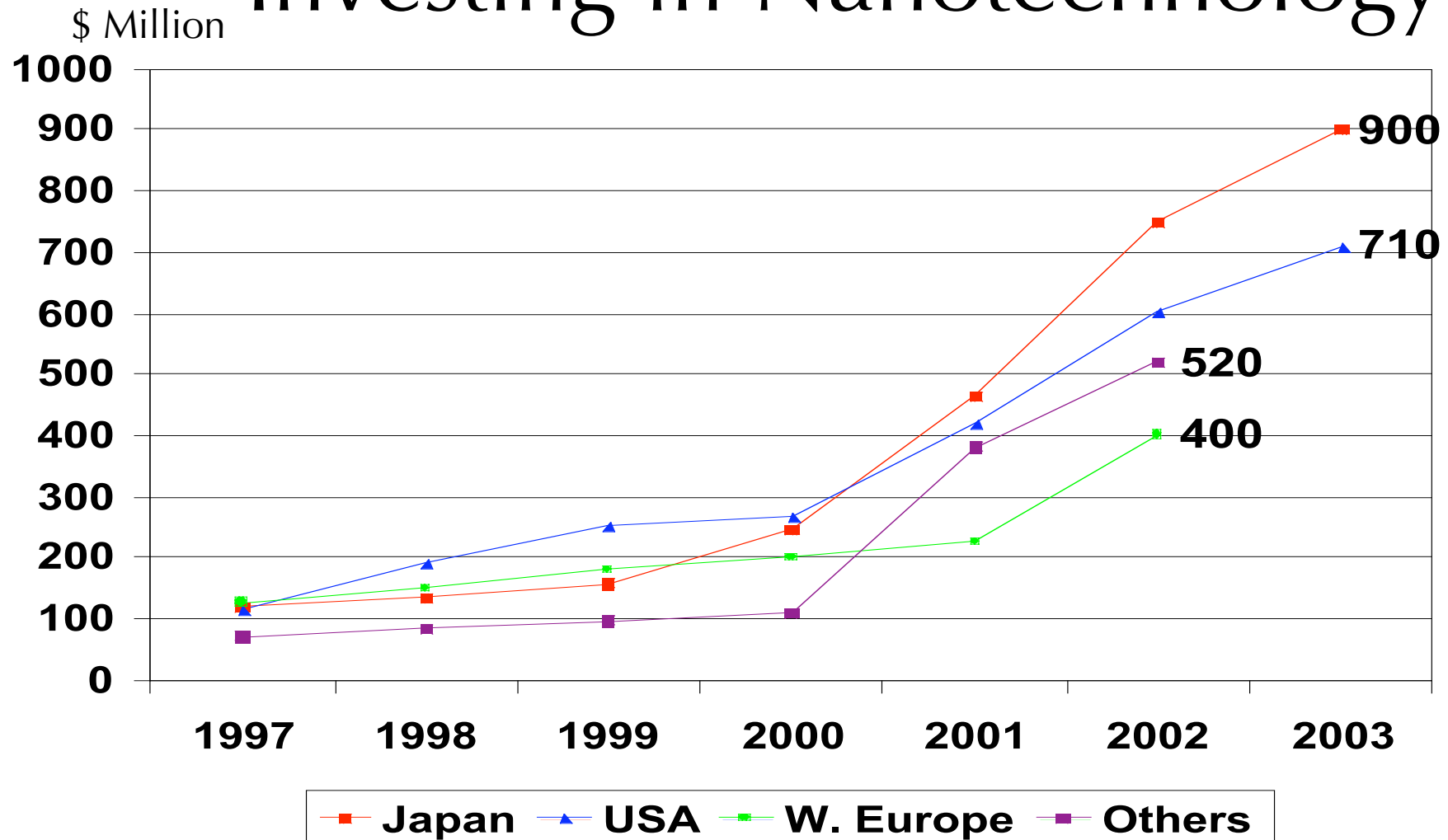
Mr. Roger Grace

Dr. Robert Warrington



Over 0.5 billion spent on patent fees

# The World's Governments are Investing in Nanotechnology



# Thank You!

Talk can be viewed online at:

<http://mems.nist.gov/Talks/USA.pdf>